An invention patented instrument for measuring capillary refilling time

Chaiyan\textsuperscript{1}, Liaohaiyan\textsuperscript{1#}, Chenrui\textsuperscript{2}, Fangyipeng\textsuperscript{3}, Guozhe\textsuperscript{1,4}, Zhanghuijuan\textsuperscript{4}, Wangxuesong\textsuperscript{1}, Wangziwen\textsuperscript{1}, Wangziyi\textsuperscript{1}, Wangzhong\textsuperscript{1,4*}

\textsuperscript{1} School of Clinical Medicine, Tsinghua University, Beijing, 100084, China
\textsuperscript{2} Guangdong Provincial Hospital of Traditional Chinese Medicine, Guangdong 510120, China
\textsuperscript{3} Laboratory of Molecular Cardiology, The First Affiliated Hospital of Shantou University Medical College, Shantou, China
\textsuperscript{4} Beijing Tsinghua Changgung Hospital affiliated to Tsinghua University, Beijing, China

\# These author have contributed equally to this work.

* Corresponding Author: Wangzhong

E-mail: wangzhong523@vip.163.com

Abstract

Microcirculation plays a critical role in organ perfusion and oxygenation. Monitoring the microcirculation is important but difficult in critically ill patients. As a method of peripheral circulation monitoring, capillary refill time (CRT) has been widely applied to evaluate the microcirculation in clinical practice. Many clinical studies have confirmed that the prolongation of CRT in critical patients is closely related to tissue perfusion and organ dysfunction. CRT is also used to monitor the peripheral circulation in neonates, diabetes, and thrombotic peripheral vascular diseases. There is a great controversy in clinic for CRT owing to the different measurements, large experimental errors, and other reasons. Our research group has designed and invented an instrument for measuring CRT. And we have obtained a national invention patent (invention patent number: 2018 1 1142255.6). Compared with manual CRT, the machine has better stability and higher accuracy in the assessment of microcirculation on critically ill patients.

Keywords

Microcirculation, Capillary Refill Time, Invention Patent
1. Introduction

Shock is a life-threatening condition with a variety of causes and characterised by an inability of the circulatory system to supply adequate oxygen and nutrients to the tissues[1]. Shock is a kind of widespread acute microcirculation failure. The identification of shock is still on the basis of clinical manifestations and macrocirculatory monitoring. Many studies have confirmed that the changes of peripheral circulatory perfusion parameters (such as CRT and skin temperature gradient) and macrocirculatory parameters (such as heart rate and blood pressure) in critically ill patients are not consistent[2]. Compared with macrocirculatory, peripheral microcirculation can indicate the hemodynamic status early[3]. An uncoupling between the macrocirculatory and microcirculation can occur in critically ill patients which affects the timeliness of diagnosis[4, 5]. Clinical symptoms, such as mottling skin, cyanosis of hands and feet, prolonged CRT, central-to-toe temperature difference (Tc-toe), can indicate microcirculation abnormalities[6].

The performing examiner applies manual pressure to the ventral surface of the distal phalanx of fingers or toes until the nailbed is blanched. This pressure is maintained for ten seconds and then released. The amount of time, in seconds, that transpires before reperfusion occurs and normal color returns to the digit is the CRT.[4]. CRT is a visual and rapid indicator of microcirculation, and the measurement of which is easy to perform[7]. CRT has been used in clinical practice since 1947 and has traditionally been measured as normal or prolonged[4]. The prolonged CRT is associated with the existence and severity of hypoperfusion and shock. In 2002, CRT was included in the assessment methods of advanced life support as part of a rapid assessment of microcirculation in critically ill children[8]. In 2017, Critical Care Medicine showed CRT was included in the management of hemodynamic support[9]. In 2019, a multicenter, observational and retrospective study showed CRT had the same ability with the qSOFA score or serum lactate concentration in diagnosis of sepsis[5]. Compared with a targeting serum lactate levels, the resuscitation strategy targeting normalization of CRT has less organ dysfunction and higher fluid responsiveness status[10]. However, the measurement of CRT is still observed with naked eye, the results were recorded as a value in seconds, and the overall measurement errors are large without the standardised ruler. As a result, the poor inter-observer agreement with wide limitations in measurement of CRT has a serious limitation to apply in practice[11].

2. The details of patent

To solve the measurement of CRT, we invented a new capillary refilling time machine and obtained Chinese National Invention Patent (invention patent number: 201811142255.6). The introduction is as follows:
2.1 Working principle

In this measuring mechanism, the MAX3010 photoelectric chip was used to emit 900nm near-infrared light signals continuously to irradiate the finger ends of the body, and detect the received signals without interruption, so as to monitor the oxygenated hemoglobin content in the blood flow of the distal capillary bed (Fig 1). A pressure device is set to pressurize the distal capillary bed. When the tip of the finger is squeezed to a certain extent, the pulse wave signal disappears and blood flow is blocked. The non-pulsating wave signal is enhanced by decreased blood flow, decreased hemoglobin content and decreased tissue thickness. When the pressure is released from the pressurizing device, the non-pulsating pulse wave signal falls back and the arterial pulse wave signal resumes. When the optical signal value returns to the baseline level before pressing, we think that the peripheral capillaries are refilled.

![Figure 1. Working principle of capillary refill time measuring mechanism](image)

2.2 Clinical significance of each parameter

The part ① in Figure2 showed the appearance of the machine and the part ② in Figure2 showed our research group marked the data S, a, b, θ, C that need to be extracted in the figures recorded by the photoelectric signal data before and after pressing (because of the data conversion, the horizontal and vertical coordinates of this figure did not set units owing to the data conversion). S represents the area under the curve of pulse wave generated by a heartbeat, which means the total amount of oxygenated hemoglobin measured in blood at the end of finger. The S value was positively correlated with peripheral blood flow at finger rip due to per-heartbeat. a represents the difference between the highest point and the lowest point of the pulse wave in the baseline state on the coordinate axis, which reflected the maximum oxygenated hemoglobin in the pulsating blood flow of the fingertip. Under the condition of certain elasticity of peripheral vessels, a value is positively correlated with the perfusion pressure of vessels, and may also be positively correlated with the mean arterial pressure. b represents the difference between the lowest point of pulse wave on the coordinate axis at baseline and the lowest point of pulse wave after pressing, and it means the difference of oxygenated hemoglobin in fingertip blood flow before and after pressing. Under the certain concentration of oxygenated hemoglobin, the b value is positively correlated with the reduced blood flow in the distal capillaries during compression. And the reduced blood flow during compression
is equal to the basic blood reserve volume of the distal capillaries. C is the time that requires for the oxygenated hemoglobin in the fingertips to return to the baseline level after pressure release., which can be equal to the artificially measured CRT value, and it is expressed as CRTauto. θ is the angle between the capillary refilling line (the straight line obtained by connecting the coordinate point of the pulse wave at the time of pressure release and the coordinate point when the pulse wave returned to the baseline) and the abscissa axis. K=\tan\theta=b/C, As the slope of the straight line, K represents the rate of oxygenated hemoglobin refilling to the capillaries after pressure release.

3. Advantages

CRT is the most intuitive index for monitoring the status of peripheral blood flow, and shows a better sensitive to hemodynamic changes than the existed indexes such as heart rate, blood pressure, cardiac output and so on[3]. In addition to the diagnosis and monitoring of shock, the other situations like diabetic peripheral vascular disease and thrombotic peripheral vascular disease can also be judged and diagnosed early by the changes of CRT. We designed and developed this CRT measurement mechanism to standardize the measurements of CRT. CRT combining with artificial intelligence technology may obtain a number of other monitoring indicators that can reflect the status of human circulation. The preliminary test showed that this mechanism could reduce the influence of pressing position, pressure, observer bias and other factors. And it also showed CRTauto had better repeatability and credibility, which can ensure the accuracy of measurement. However, the repeatability and credibility of S and a values need to be further studied and verified, and their bias may be related to the finger position and the state of microcirculation during the sampling in the current experiments. So we will continue to complete the software design of data extraction, improve the measurement fingers and other problems and observe the characteristic parameters. We will verify the repeatability and credibility of S, a value, and explore the clinical application of S, a, b, C, CRTauto and other parameters.
4. Summary

CRT is one of the important indicators of peripheral microcirculation. Which can be used to judge a variety of pathophysiological conditions, including neonatal circulation monitoring, diagnosis and detection of shock, detection of peripheral microcirculation of diabetes, detection of thrombotic peripheral vascular disease and so on. In the treatment of critically ill patients, the improvement of microcirculation is the ultimate goal of hemodynamic therapy. As a direct evaluation index of peripheral circulation perfusion, CRT can be used independently or combining with other peripheral circulation perfusion indexes, such as limb end temperature, which is helpful for early identification and prognosis of critically ill patients. However, there are many problems in the CRT evaluation technology. Compared with the traditional evaluation CRT, the patented capillary refilling time measuring instrument of the utility model has higher reliability and stability, and is worth popularizing and using in clinic.

Funding

This study was supported by the grants from Institute of Precision Medicine of Tsinghua University [10001020125]
References